# *Atmospheric Physics I*

- 2c. Compute the wind direction and speed on vector diagrams.

# *Scalar and vector quantities*

- Any physical quantity (such as temperature, density or humidity) which has only magnitude (a single numerical value), but *without direction,* is a scalar quantity. (Example: 45 mph, or 500°F.).

# *Scalar and vector quantities*

- Examples of scalar quantities:
  - Distance – the measurement of the separation of two points. Units: meters (m)
  - Area (A) – the measurement of a two dimensional surface. Units: meters squared ($m^2$)
  - Volume (V) – the amount of space that an object occupies as measured in cubic units. Units: meters cubed ($m^3$).

# *Scalar and vector quantities*

- Scalar quantities (cont)
  - Speed – m/s, mph – the rate at which a distance is covered, the numerical value or magnitude of velocity.
  - Density – the amount of mass per unit volume. Symbolized by the Greek letter rho (ρ).
    - Equation: $\rho = \frac{m}{V_{ol}}$
    - Terms
      - m is the mass of the substance
      - $V_{ol}$ is the volume which it occupies
    - Units: $kg/m^3$

# *Scalar and vector quantities*

- Variable relationships
  - Density is directly proportional to mass (if volume is held constant).
    - An increase in mass will cause an increase in density.

$$\uparrow \rho = \uparrow m/V$$

    - A decrease in mass will cause a decrease in density.

$$\downarrow \rho = \downarrow m/V$$

# *Scalar and vector quantities*

– Density is inversely proportional to volume (if mass is held constant).

An increase in volume will cause a decrease in density.

$$\downarrow\rho \quad \frac{\dot{m}}{\Uparrow V_{ol}}$$

- A decrease in volume will cause an increase in density.

$$\uparrow\rho \quad \frac{\dot{m}}{\Downarrow V_{ol}}$$

# *Scalar and vector quantities*

- Examples: $\rho \frac{m}{V_{ol}}$

  – If the mass were doubled, what would happen to the density? What happens to the volume?

  – If the volume is increased to 5 times the original value, what happens to the density? What happens to mass?

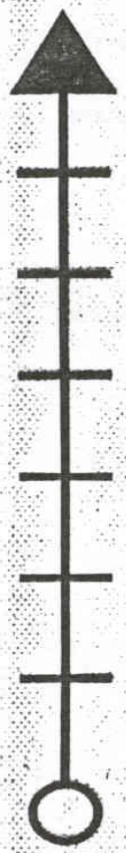
# *Scalar and vector quantities*

- Any quantity (such as force, velocity, or acceleration) which has both magnitude and direction is a vector quantity. Example: a car moving north at 45 mph, or a wind of 8 knots toward 280°

# *Scalar and vector quantities*

- Representing vectors (in 2-dimensions)
  - Mathematically
    - 2708 (Westward at 8 knots)
    - A vector is represented in this unit by a symbol in boldface (i.e. **y**).
    - Also, it can be represented by placing a half arrow above the symbol (i.e. “ $\vec{y}$ ”)
    - The magnitude (numerical value) of a vector is represented by vertical lines surrounding the symbol (i.e. |y|).

# Vector Representation



A car is moving North at 70 m/s

Scale
5mm = 10m/s

toward 360°
at 70 m/s

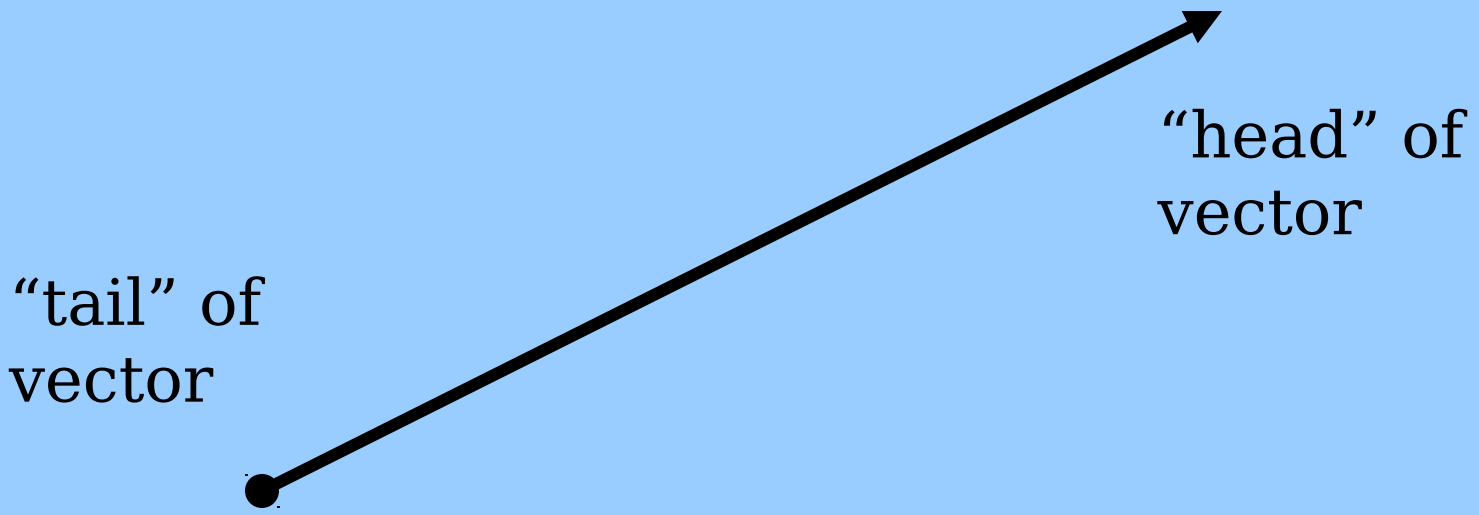
Graphically

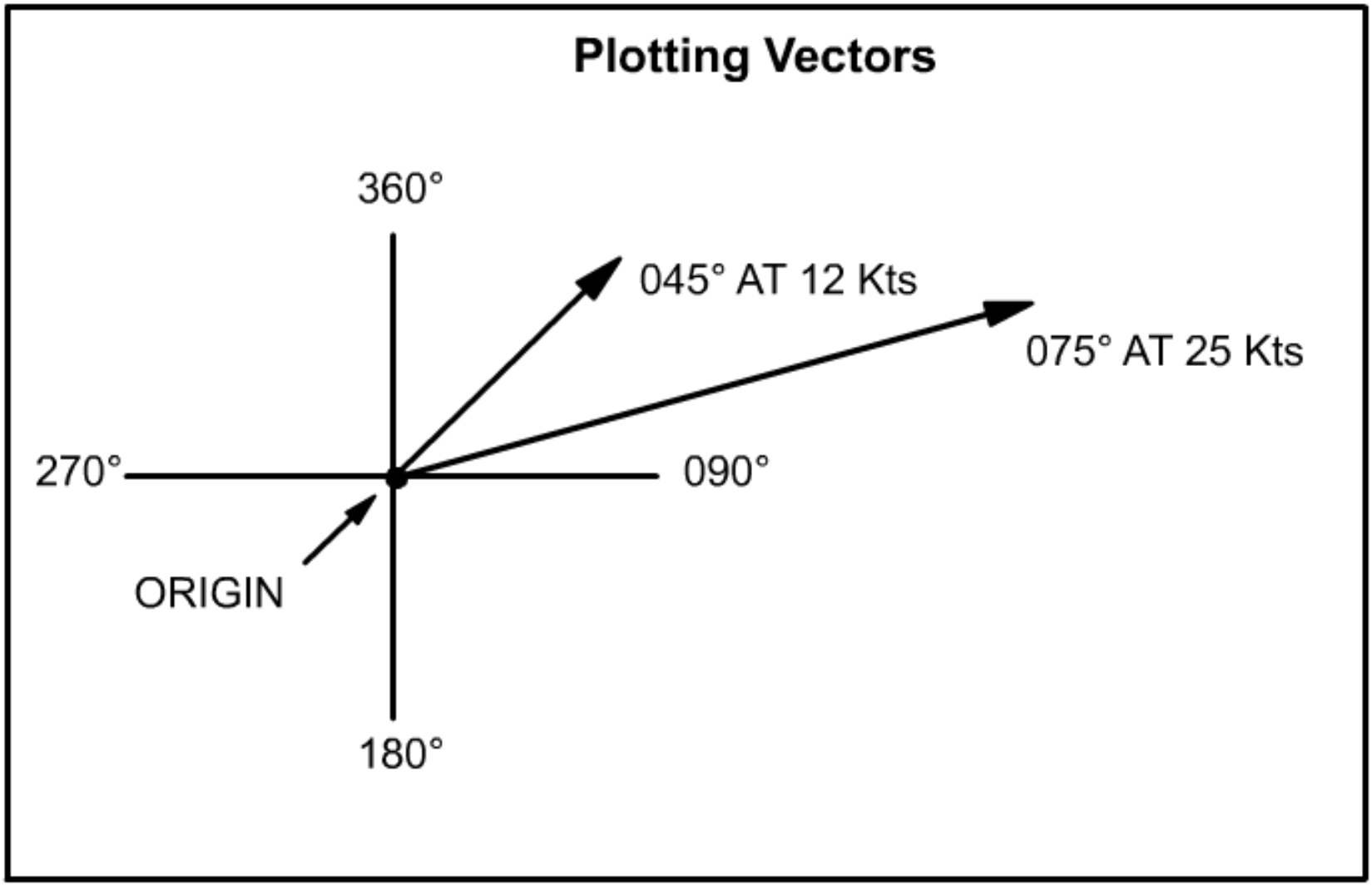
Mathematically

# *Scalar and vector quantities*

- Representing vectors (cont)
  - Graphically (This is the method we will be using.)
    - The vector is represented using an arrow:
    - With its length proportional to the magnitude of the vector.
    - Pointing toward the direction an object is moving or in which a force is being applied.
    - Plotted on a coordinate system to ensure all vectors are represented in the same scale and correct orientation.

# Anatomy of a Vector




Plotting Vectors
360°
045° AT 12 Kts
075° AT 25 Kts
270°
090°
ORIGIN
180°

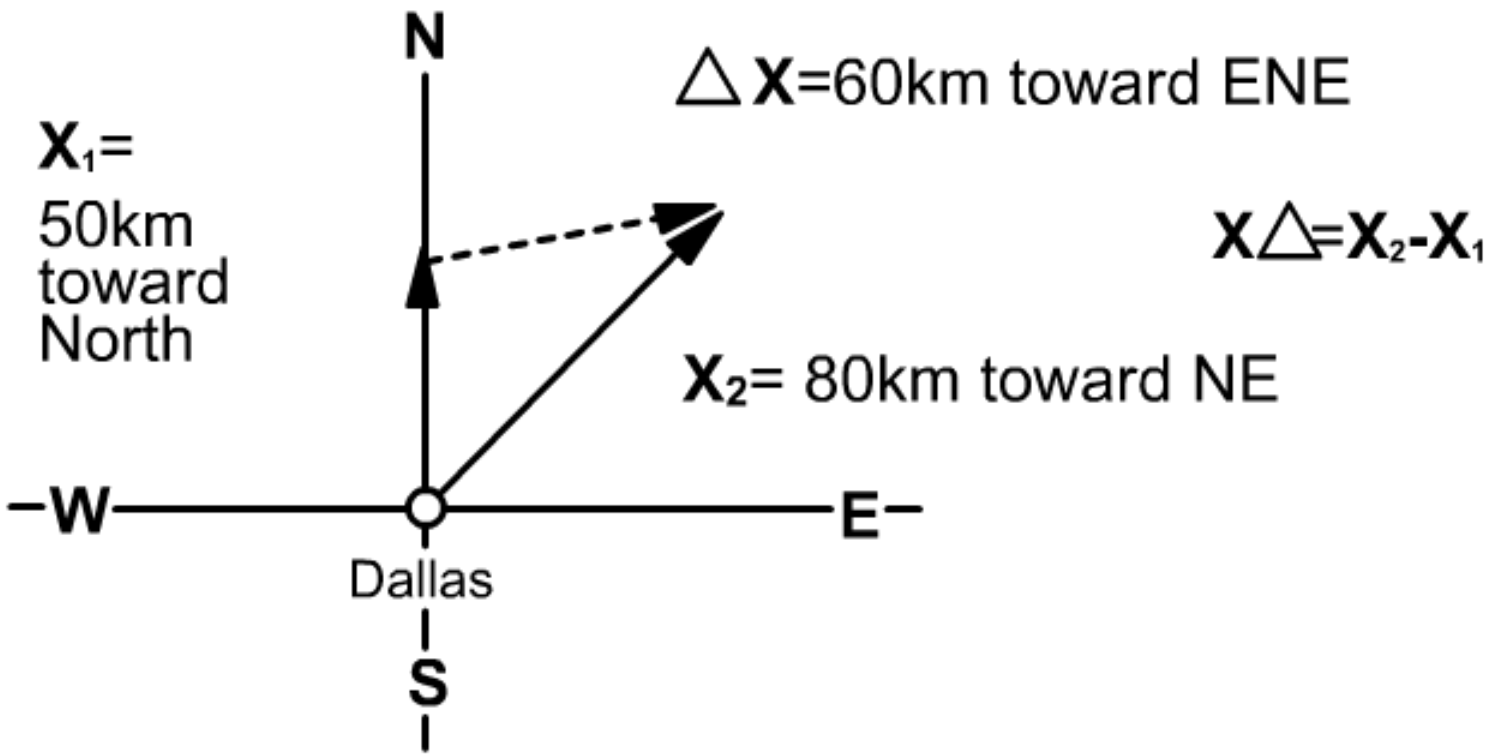
# *Scalar and vector quantities*

- Representing vectors (cont)
  - Graphically
    - Axis – one of two perpendicular lines used to define the coordinate system. For our examples, one axis runs west to east and the other north to south. Vectors are plotted toward the direction given based on compass directions
    - Origin – the intersection of two axes. The end point of the vector is plotted at the origin.

# *Scalar and vector quantities*

- An example of a vector:
  - Velocity (V) – Displacement per unit time. Speed and direction of a moving object.
    - Vector quantity ($\mathbf{V}$ **Boldface** Type Identifies a Vector).
    - Average velocity ( $\overline{V}$ ) – displacement over some time interval. The bar over the symbol denotes an average value.

## Displacement (△X)



# *Scalar and vector quantities*

- Computing the magnitude.
- Equation: $V = \frac{\Delta x}{\Delta t}$

  toward the east where $\Delta t$ is the time interval.

  - The magnitude (speed) is determined by $|V| = \frac{|\Delta x|}{\Delta t}$
  - The direction is that of the displacement.
  - Units: length/time – m/s

# *Scalar and vector quantities*

- Variable relationships
  - ***If time is held constant***, velocity is directly proportional to displacement.

    » An increase in displacement will cause an increase in velocity:

    $$\uparrow V = \frac{\uparrow \Delta x}{\Delta t}$$

    » A decrease in displacement will cause a decrease in velocity:

    $$\downarrow V = \frac{\downarrow \Delta x}{\Delta t}$$

# *Scalar and vector quantities*

- Variable relationships
  - ***If displacement is held constant***, velocity is inversely proportional to the time change.

    » An increase in the change in time will cause a decrease in velocity:

    $$\frac{\Delta x}{\uparrow \Delta t} = \downarrow V$$

    » A decrease in the change in time will cause an increase in the velocity:

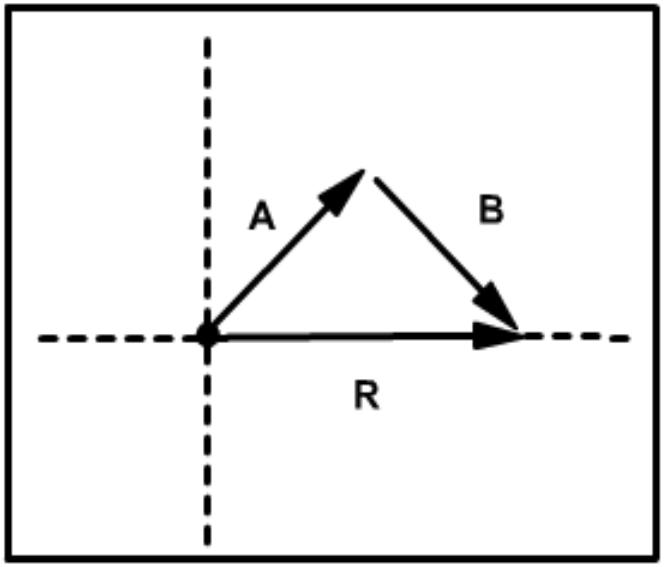
    $$\frac{\Delta x}{\downarrow \Delta t} = \uparrow V$$

# *Vector Operations (**Boldface** Type indicates a vector)*

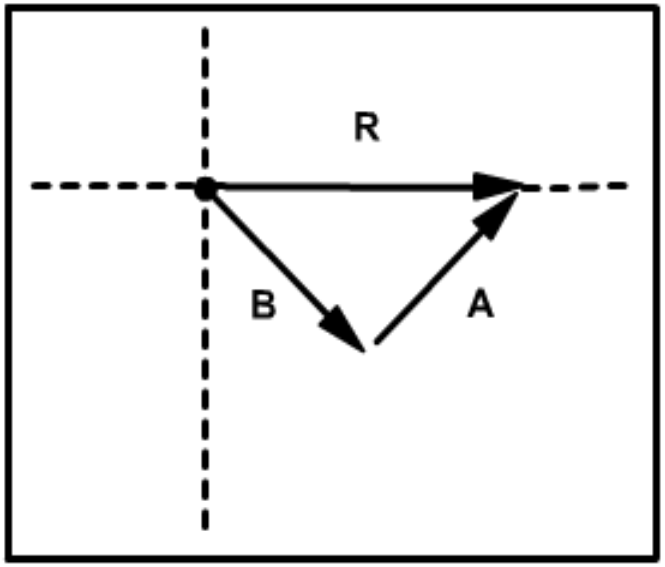
- Vector addition **(A+B)** – "head to tail" method.
  - Construct x, y, coordinate system
  - Select a scale & plot vector "**A**" to scale.
  - Plot vector "**B**" to scale, with proper orientation using another coordinate system on the head of vector "**A**".
  - Draw resultant vector "**R**" from origin of "**A**" to the head of last vector being added "**B**".

# HEAD-TO-TAIL

Ex. **A** = 045°/20, **B** = 135°/20,
Resultant, **R** = 090°/28.3kts




**A + B = R**




**B + A = R**

# *Vector Operations*

- Vector addition **(A+B)** (cont)
  - Note, the order of addition makes no difference: **A + B = B + A = R**

# *Vector Operations*

- Two meteorological uses for vector addition:
  1. Resultant of forces:
     - The direction of a parcel's movement will be in the direction found by the vector sum of all of the forces acting on the parcel.
     - The magnitude of the change in the parcel movement is proportional to the magnitude of the resultant.

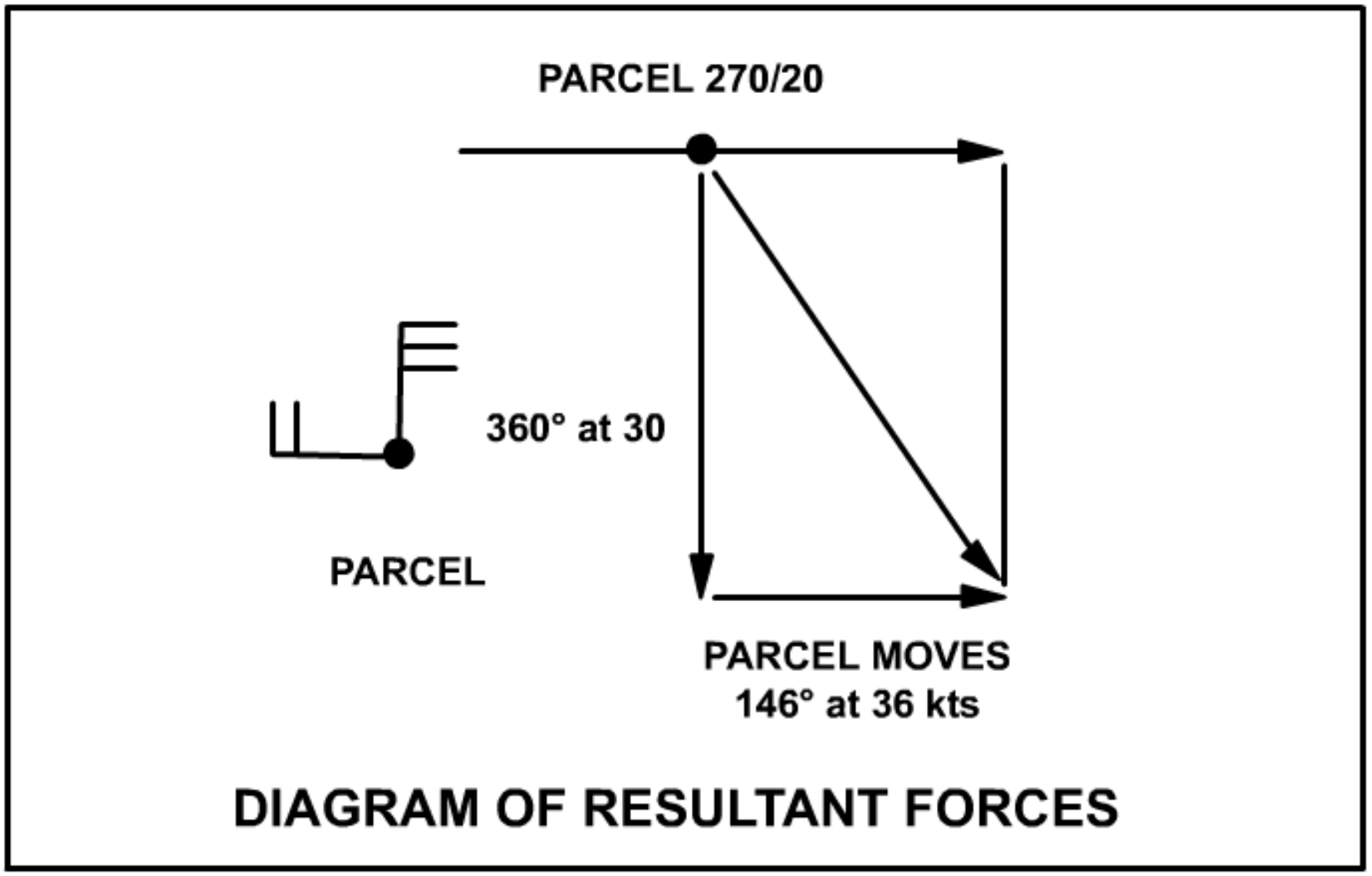



DIAGRAM OF RESULTANT FORCES

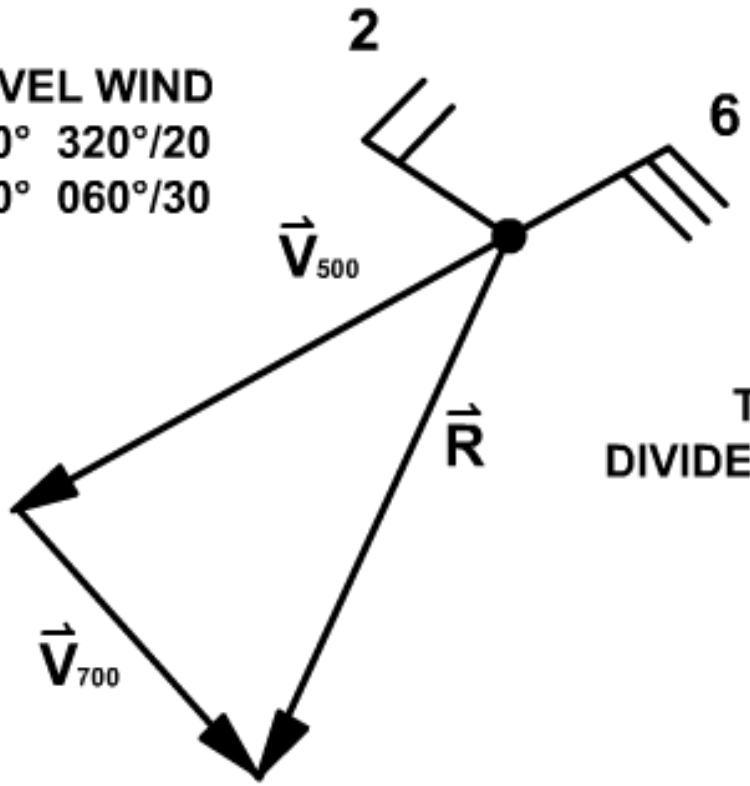
# *Vector Operations*

- Two meteorological uses for vector addition:

  2. Average wind for a layer
     - The magnitude, or speed, of the resultant wind is divided by the number of levels added to compute the average wind for a layer.
     - $(v_1 + v_2)/2$ = Average wind. e.g. the average wind for the layer from 700mb to 500mb would be: $(v_{500}+v_{700})/2$.

# Average wind for a layer

LEVEL WIND
700° 320°/20
500° 060°/30




R = 210° AT 34kt
IN TERMS OF A WIND
030 AT 34KT

TO FIND THE AVERAGE,
DIVIDE THE MAGNITUDE ONLY BY 2

AVERAGE WIND

AVERAGE WIND = 030° at $(\frac{34}{2})$ = 17kt

# *Vector Operations*

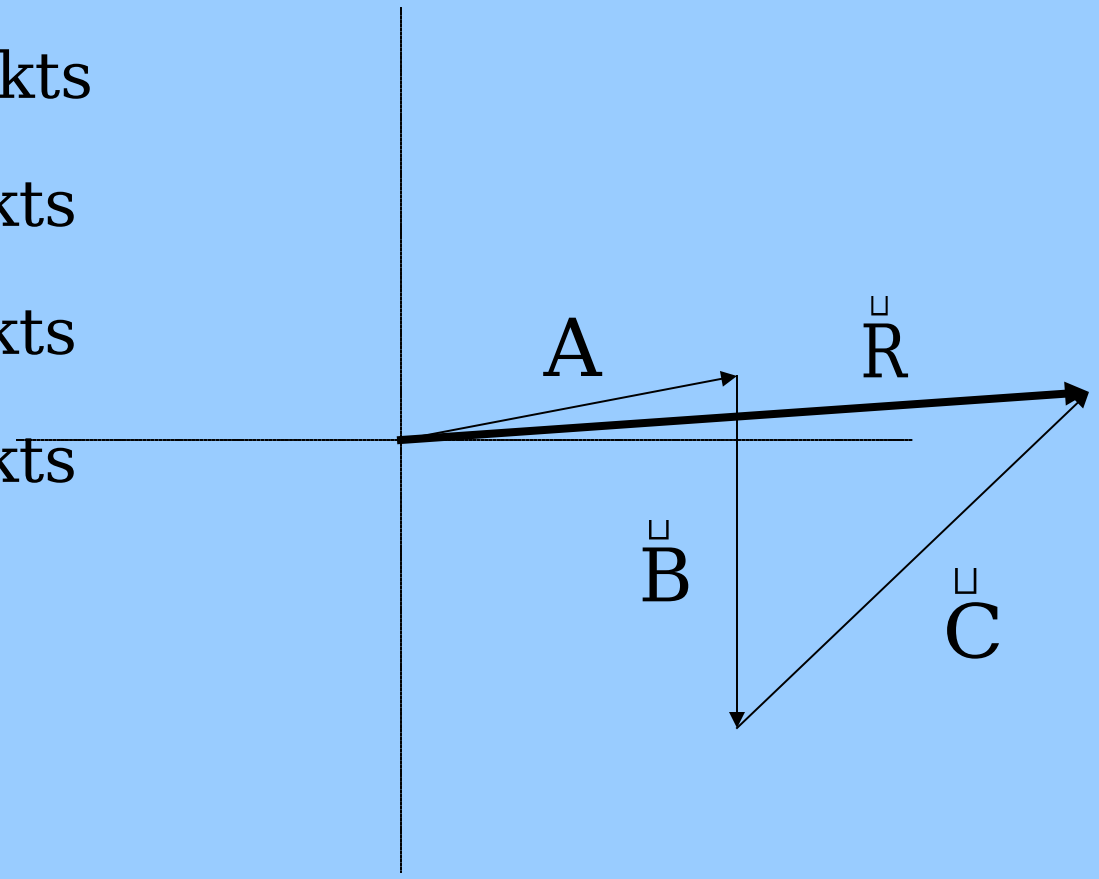
- Addition of three or more vectors may be accomplished using the same “head-to-tail” method previously discussed.
  - Again, the order of addition does not make a difference.
    (Example: **A** + **B** + **C** = **C** + **B** + **A** = **R**.)
  - The addition of several vectors is useful in areas that involve a combination of meteorological operations.
  - If an average speed is necessary, the resultant speed must be divided by the number of vectors.

$\underset{\sim}{A}$ 070 at 15 kts

B 180 at 15 kts

C 045 at 20 kts

R 080 at 28 kts



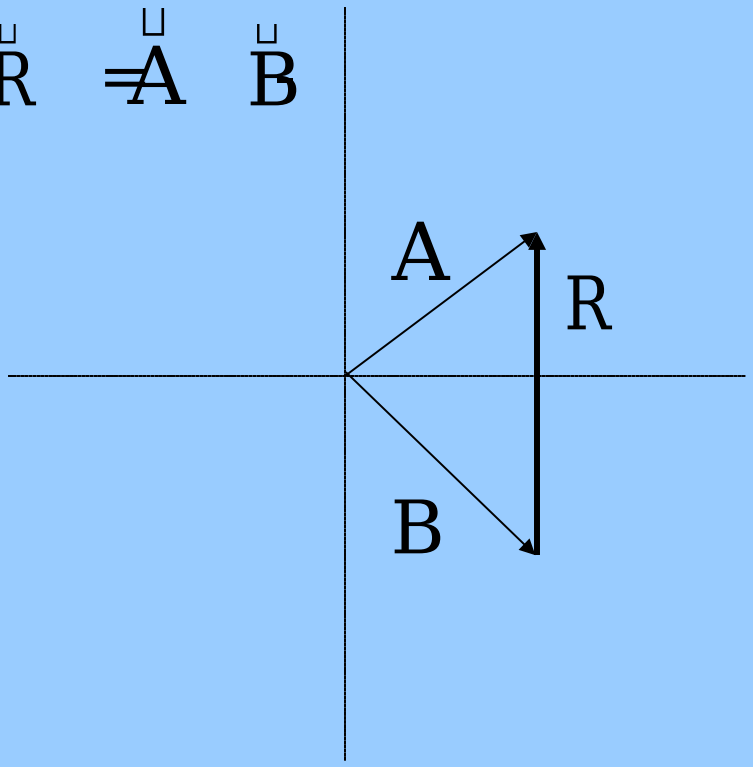

***ADDITION OF THREE OR MORE VECTORS***

# *Vector Operations*

- Vector subtraction (**A** – **B**)
  - The “tail to tail” method of vector subtraction.
    - Construct x, y coordinate system.
    - Select scale and draw both “**A**” and “**B**” to scale with both tails at the origin of the coordinate system.
    - Draw resultant “**R**” from the head of the vector being subtracted, “**B**” to the head of the vector being subtracted from “**A**”.

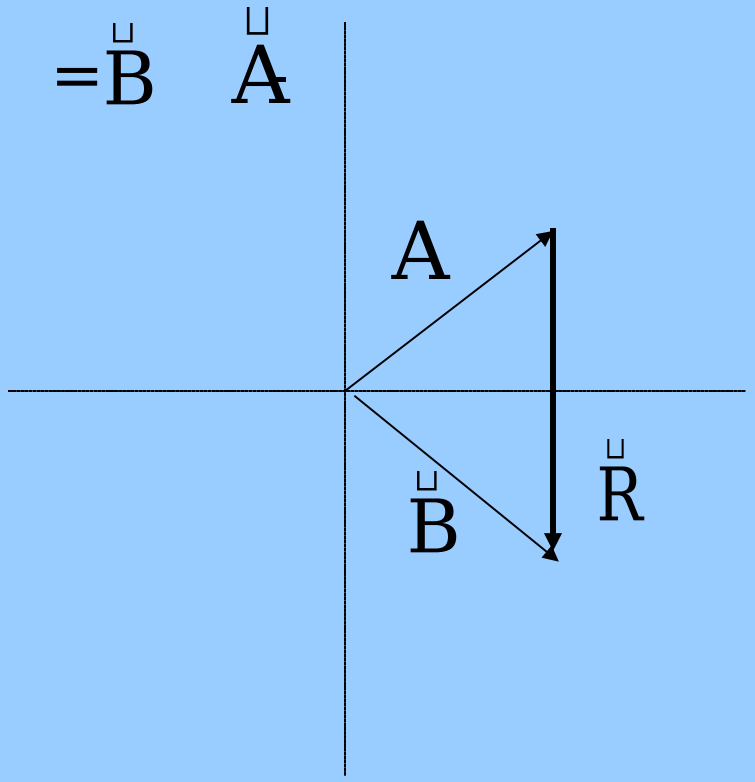
# *VECTOR SUBTRACTION*

$\vec{R} = \vec{A} - \vec{B}$




$\vec{R}$ = 360 at 21 kts

$\vec{R} = \vec{B} - \vec{A}$




$\vec{R}$ = 180 at 21 kts

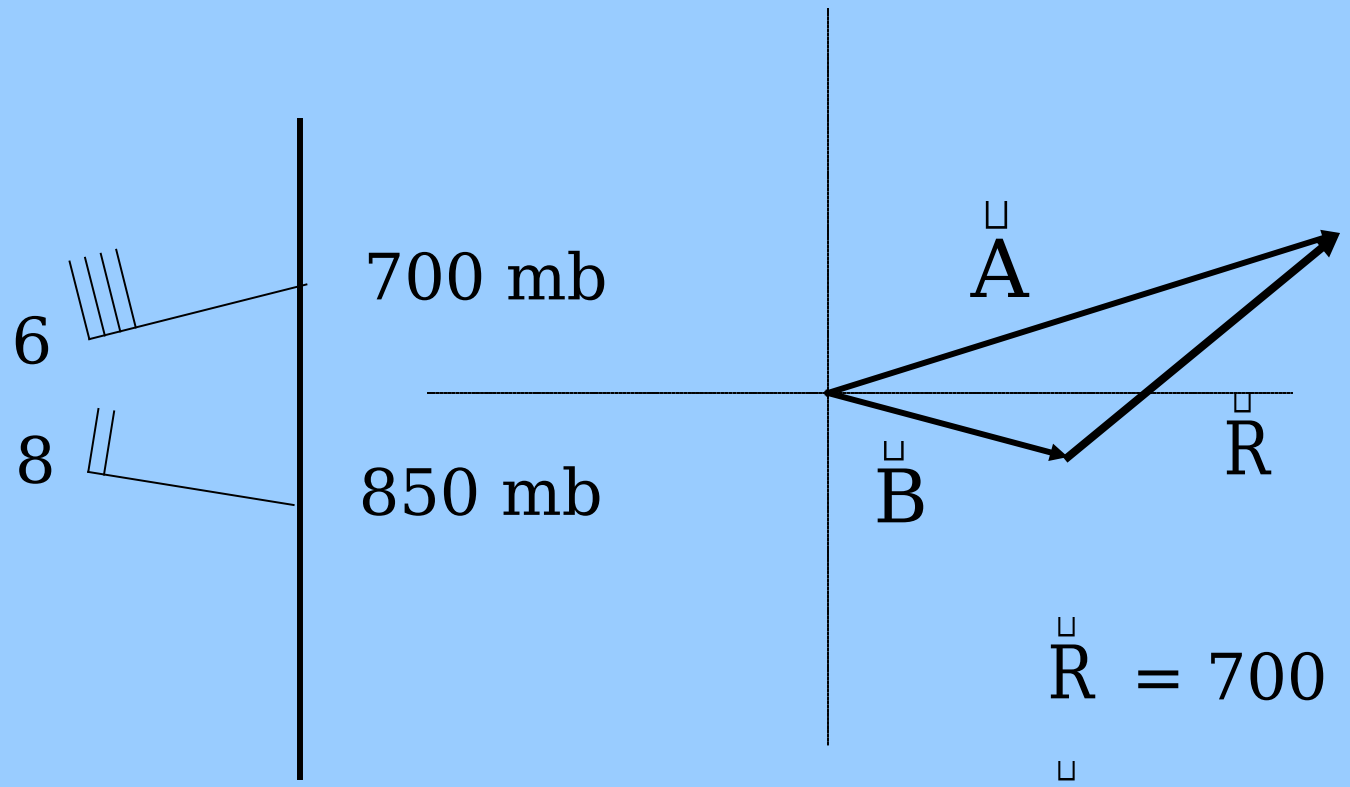
# *Vector Operations*

- Vector subtraction (**A – B**)
  - **THE ORDER <u>DOES</u> MAKE A DIFFERENCE!: A – B** does not equal **B – A.** (the magnitudes of R would be the same, but direction would be 180° out.)

# *Vector Operations*

- Vector subtraction (**A** – **B**)
  - Meteorological uses
    1. Wind shear – definition: the change of wind speed and/or direction, in the vertical or horizontal (upper minus lower).

# *Vertical Wind Shear on Skew-T*




$\vec{R}$ = 700 - 850

$\vec{R}$ = 055 at 25 kt

# *Vector Operations*

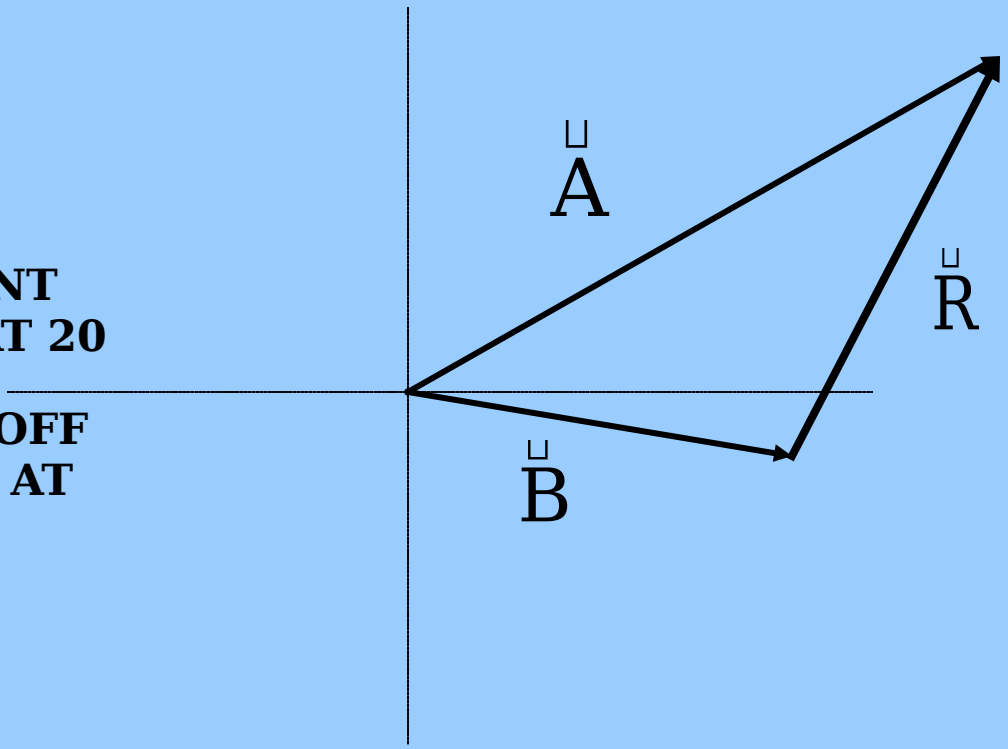
2. Movement of cirrus blowoff – wind flow aloft minus cell movement (upper minus lower)
   - Cirrus starts at the origin and is blown off by the upper-level wind flow, vector "**A**"
   - During the same time, the thunderstorm moves along vector "**B**"
   - From the viewpoint of the thunderstorm (or as seen from a satellite), it appears that CI has blown off in direction "**R**"

# *Cirrus Blowoff*

$\vec{A}$ **WINDS ALOFT FROM 240 AT 30 KT**

$\vec{B}$ **CELL MOVEMENT TOWARD 100 AT 20 KT**

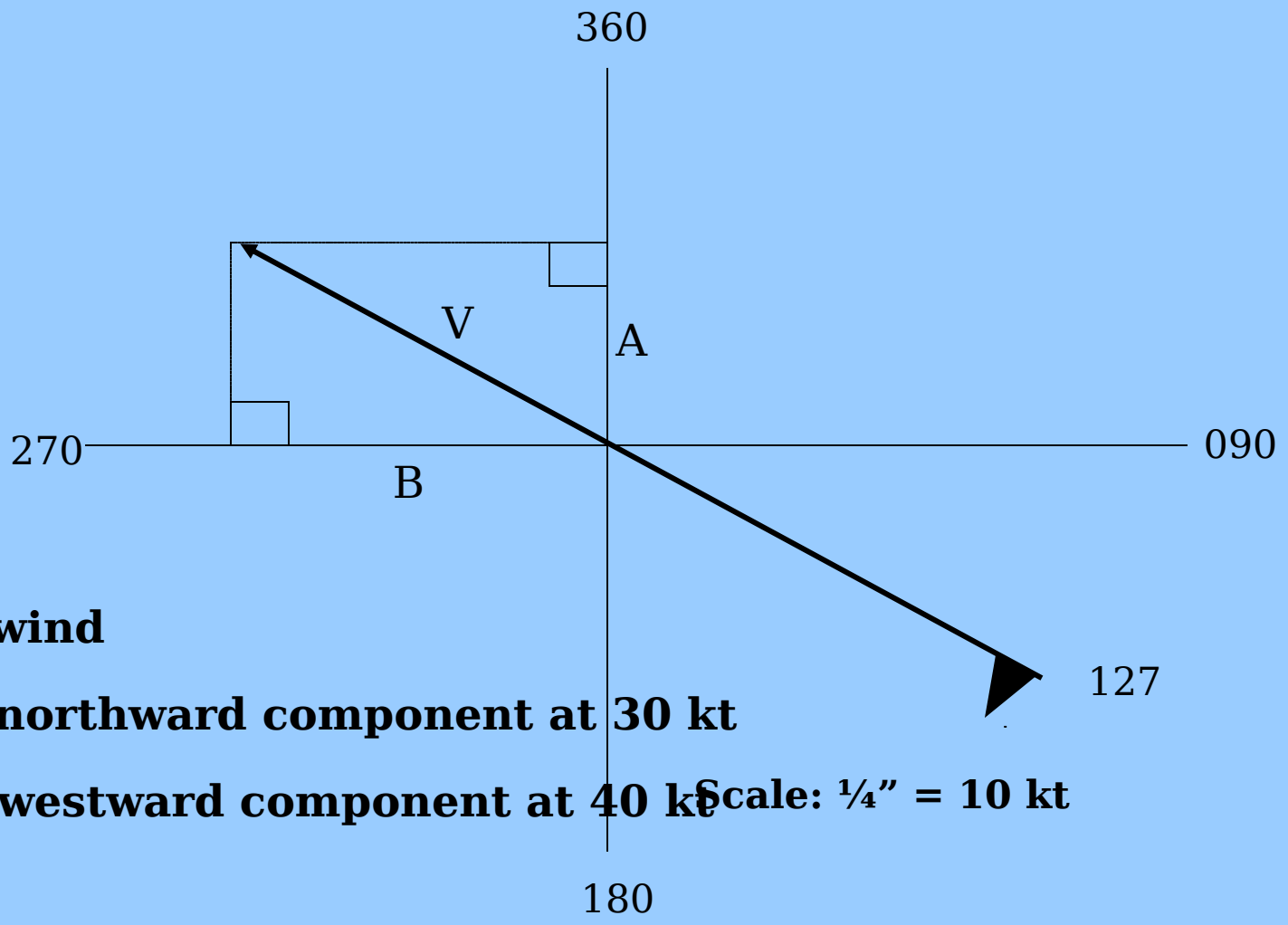
$\vec{R}$ **CIRRUS BLOWOFF** $\vec{A} + \vec{B}$ **= 020 AT 19.5 KT**



# *Vector Operations*

3. Computing components of vectors.
   - Component – the portion of a vector along a given coordinate direction (north-south and east-west). Note: The sum of the components yields the vector.
   - Determining vector components graphically.
     - Draw a navigational coordinate system
     - Determine plotting scale
     - Plot vector from origin.
     - Drop a line from the head of the vector perpendicular to each axis.
     - Determine the magnitude of each component.
     - Determine the direction of each component.

# *Computing Vector Diagrams*




**V: wind**

**A: northward component at 30 kt**

**B: westward component at 40 kt**

**Scale: ¼” = 10 kt**

# *Vector Operations*

3. Computing components of vectors. (cont)
   - Commonly used terms.
     - Air speed – the speed at which an aircraft is flying relative to the air.
     - Ground speed – The speed at which an aircraft is flying over (or relative to) the ground (actual speed).
     - Head wind – component of the wind vector which
       - is **parallel** to the aircraft's direction of motion
       - Opposes the aircraft's motion
       - Will result in a decreased ground speed.

# *Aircraft with No Wind and an aircraft with a Head*

## ***No Wind***

Air speed = Ground speed
(AS) (GS)

**AS = 200 kt**

**GS = 200 kt**

**200 kt**
**AS = GS**
**WS = 0**

## ***Head Wind***

Air speed – Head wind = Ground speed
(AS) (WS) (GS)

9

**WS = 50 kt**

**AS = 200 kt**

**GS = 150 kt**

# *Vector Operations*

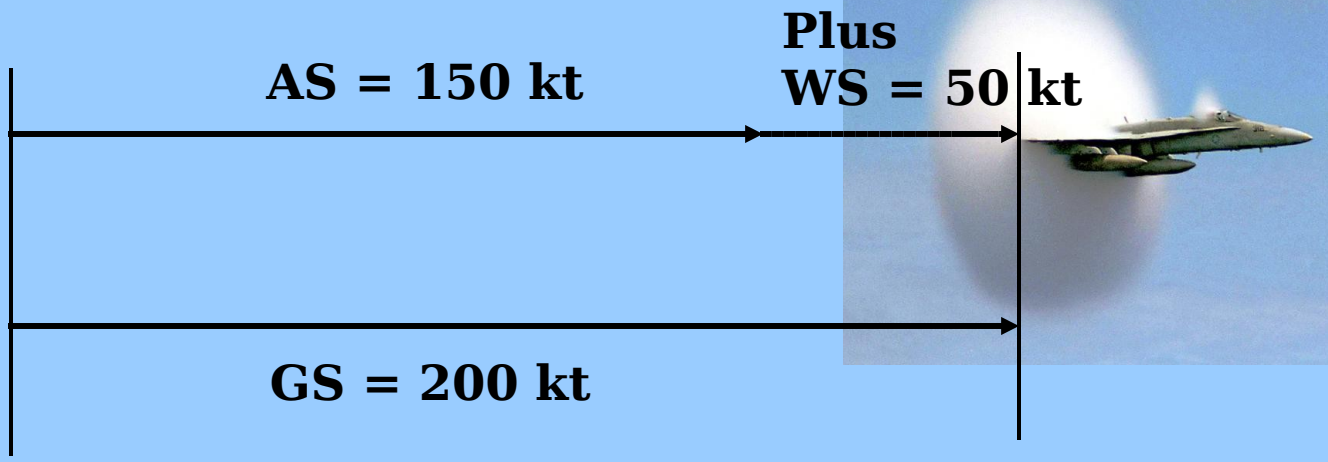
3. Computing components of vectors. (cont)
   - Commonly used terms.
     - Tail wind – component of the wind vector which
       - » Is parallel to the aircraft's direction of motion
       - » Assists the aircraft's motion
       - » Will result in a increased ground speed
     - Cross wind – Wind component which is perpendicular to an aircraft's flight path. Will require a change in the aircraft's heading in order to maintain the desired course

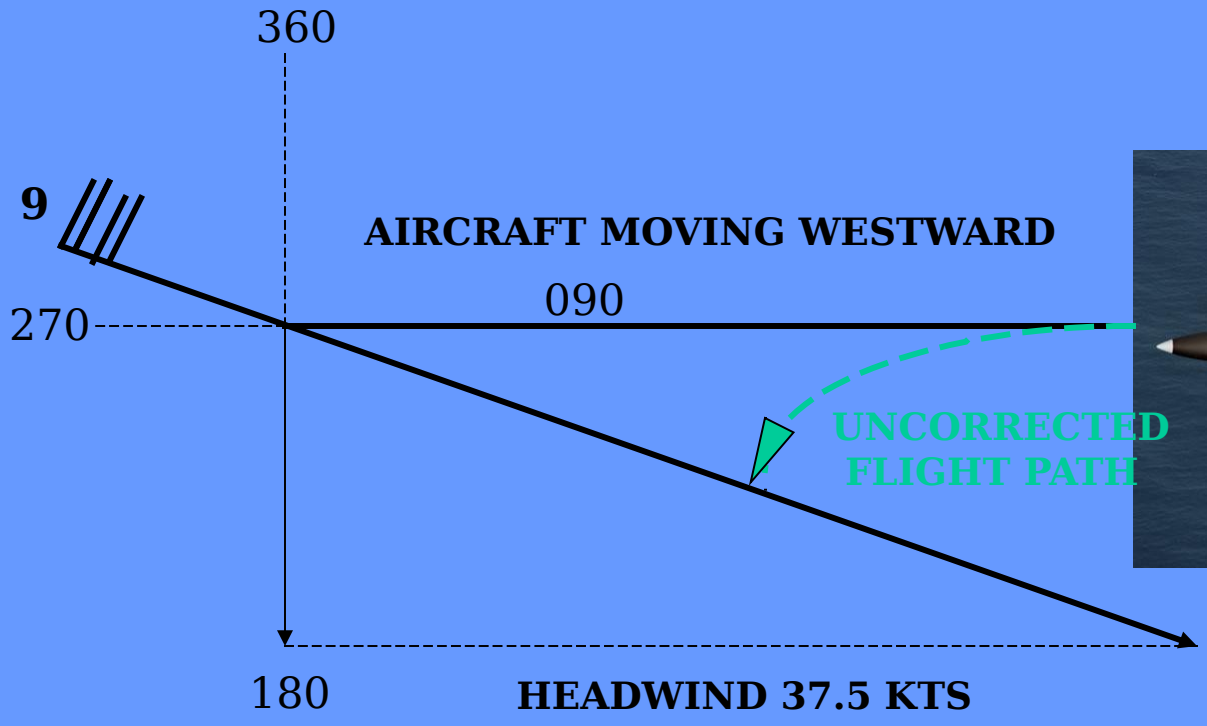
# Aircraft with a Tail Wind

**TAIL WIND**
**WS = 50 kt**

**(AS) (WS) (GS)**

**Air speed + Tail Wind = Ground speed**

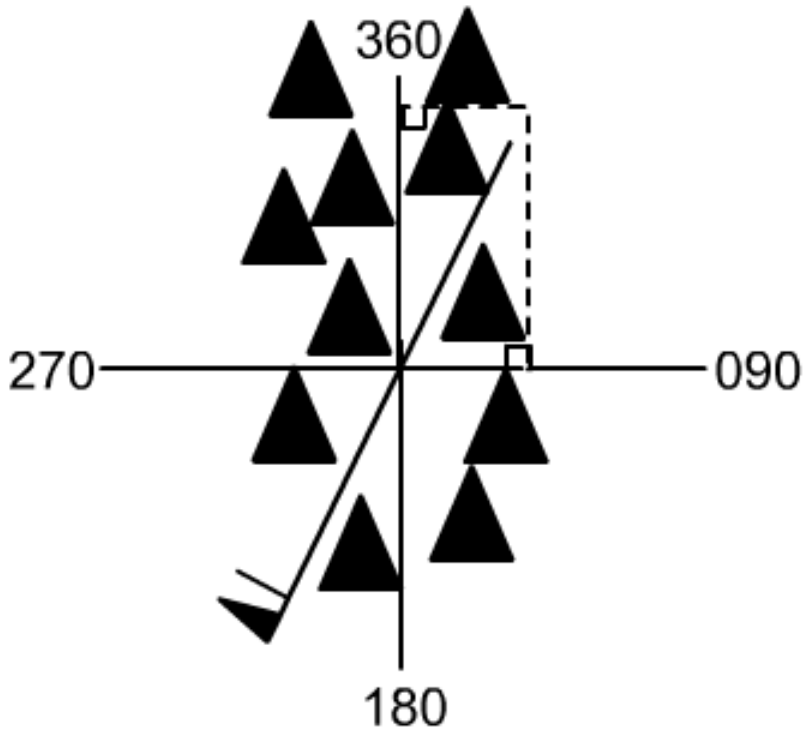




# *Aircraft with a Crosswind*

# *Vector Operations*

3. Computing components of vectors. (cont)
   - Commonly used terms.
     - Runway cross wind – Wind component which is perpendicular to the runway. May make flight operations on the runway unsafe.
     - The strength of the wind component perpendicular to a mountain r ange often has a definite impact on lee-side (downstream side) weather patterns and downstream turbulence, as you will see later in the course.



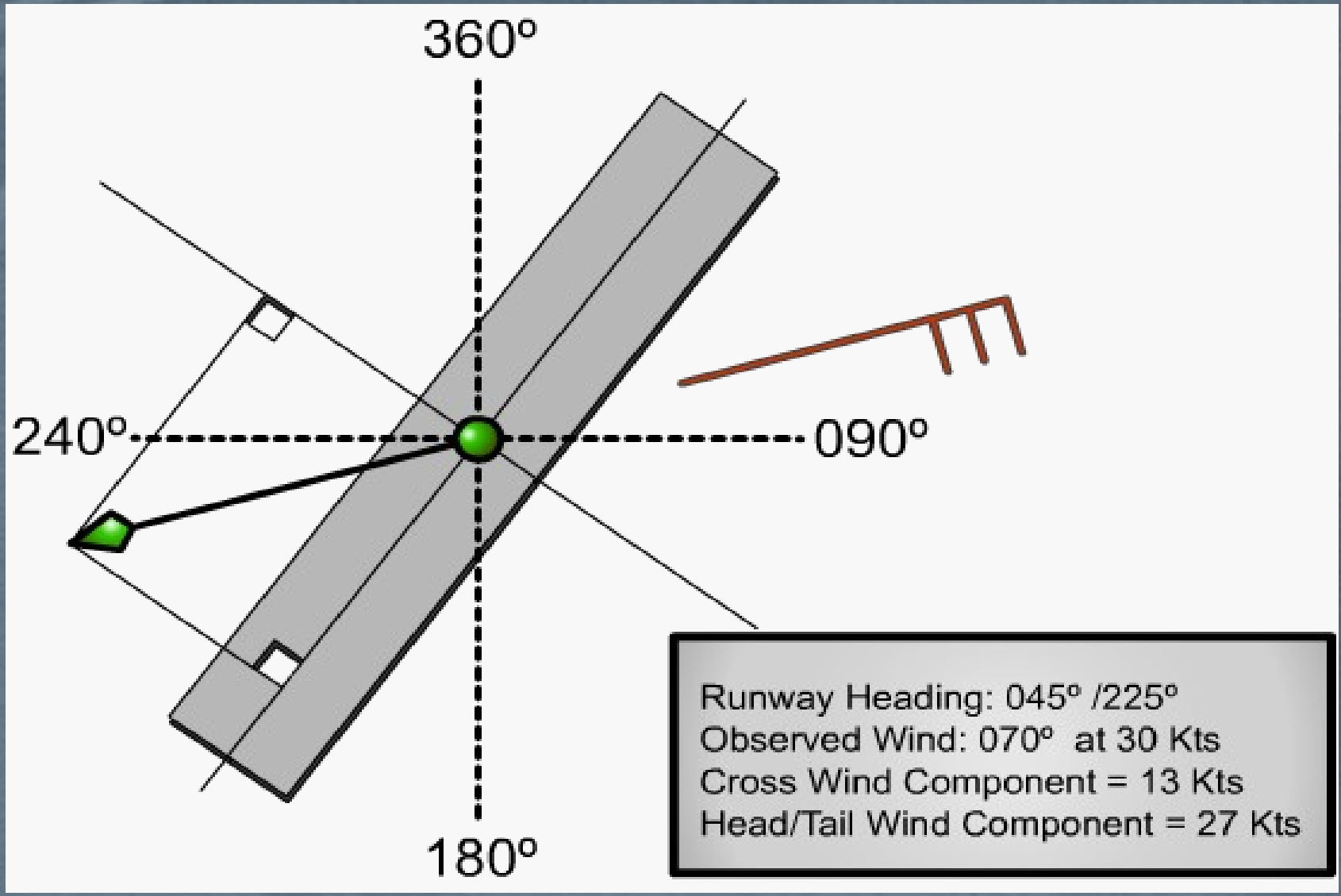

Observed wind
from 210/60

component perpendicular
to the mountain range
30kt toward 090°

Scale 1/4"=20kt

# *Vector Operations*

4. Determining wind components relative to non-standard reference frames.
   - Plot the observed wind and the direction of motion of the aircraft or orientation of the runway, mountain range, etc. on a navigational coordinate system
   - Draw a second coordinate system over the first one with one axis parallel to the flight path, runway, etc.


360°
240°
090°
180°
Runway Heading: 045° /225°
Observed Wind: 070° at 30 Kts
Cross Wind Component = 13 Kts
Head/Tail Wind Component = 27 Kts

# *Vector Operations*

4. Determining wind components relative to non-standard reference frames. (cont)
   - From the head of the plotted wind vector draw vector components at right angles to the second coordinate system.
   - The vector component perpendicular to the aircraft is the crosswind and the parallel vector component is the head or tail wind.

- Assign Review Exercise in WB-100
- Administer and evaluate Appraisal 102b.